Database Development for Ocean Impacts: Imaging, Outreach, and Rapid Response

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http://csi.whoi.edu

LONG-TERM GOALS

The primary goal for this project is to provide a web-accessible database on the anatomy and physiology of marine mammals, their prey species, and other endangered marine species for which there are concerns for underwater acoustic impacts.

OBJECTIVES

The scientific objective of this project is to provide an on-going resource for research, resource management, and environmental agencies as well as the Defense and industry communities. Access to these data will improve the accuracy of models and representations of marine species anatomy and our understanding of the structure and function, both normal and as altered by disease or impacts from sound, toxins, or trauma. These data provide a reference library for impact assessments as well as aids for training veterinarians, scientists, and stranding responders and assist in the standardization of procedures, measures, and protocols for descriptions of strandings which will as improve our understanding of and response efficacy to stranding events. This effort provides to the scientific community, stranding network, fisheries agencies, and public a resource that comprises educational tutorials of anatomy and pathology at the lay and professional scientific level, clinical case histories, critieria for determination of normal vs abnormal findings for *in vivo* and post mortem conditions, and instructional manuals on imaging procedures and morphometric research methodologies

APPROACH

The current version of the proposed database (http://csi.whoi.edu) was launched publicly May 2011. It was initiated through funding by the Marine Mammal Program of ONR with additional support by the EnvDiv/CNO N45 of the US Navy. Much of the projected goals are met or near completion. However, as the website evolved, it became apparent that to achieve its overall goal, it is necessary to expand the data and case material to include *in vivo* imaging and instructions, micro imaging developments, and new display modes on-line that enhance appreciation and use of the material by the public and research communities.

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In addition to the main objectives listed above, two other significant roles have developed for the website: 1) to provide on-line and downloadable tutorials and case studies on procedures for examining stranded animals, and 2) to provide both data and a locus for exchange of data and research findings related to use of biomedical images in basic and applied research on topics related to sound and sensory systems. As a consequence, the approach has evolved from providing a catalog of baseline images and related publications to users to now include interactive displays, tutorials, videos, and sound files.

WORK COMPLETED

The current version of the proposed database (http://csi.whoi.edu) was launched publicly May 2011. It was initiated through funding by the Marine Mammal Program of ONR with additional support by the EnvDiv/CNO N45 of the US Navy.

Site Configuration

The Database website is hosted on a local WHOI Apache web server (cetus.whoi.edu) for Drupal based Content Management System (CMS). Base configuration of a dynamic MySQL database structure that serves the website content is complete with security and backup configurations updated daily by WHOI Computer Information Services.

Security

Because the site combines areas of public access for open education but also sensitive case data, multi-level security measures are required. Server side daily monitoring of the site includes traffic reporting intrusion detection; file permission status; and denial of service attempt monitoring. Host side security modules include spam (including email obfuscation; auto detect and spam submission prevention (CAPTCHA); user profile editing protection, user content access control; login security; secure site integration for site privatization and secure remote access to RSS feeds. Case data and consults on images are provided through secure login on site to FTP servers and via password protected compressed data transmission through Dropbox.

Backup:

Server side daily backup of the entire site is obtained through WHOI Computer Information Services.

Content

The open database at present provides examples of 2D CT images, 3D reconstructions, videos, and interactive anatomy as well as tutorials and manuals on scanning and necropsy procedures and photos of the scanning process, field, and laboratory dissections. More comprehensive data on diagnostic findings for stranding cases are available under the sections on pathologies. Whole animal data sets and multi-segmented images related to FEM model development are found in the video, 3D, and model sections of the website. These images are linked to extensive case file data that provide more advanced research relevant accessible to registered users.

The site currently comprises the following:

- 6754 Case Images
- 43 Animations/videos
- 18 Interactive anatomy tutorials

- 97 Specimen Data Summaries and official Case Reports
- 127 Publications available for review and download

Content included in the database and available to end users includes CT images and digital photos of scanning processes and field and laboratory dissections of selected cases as well as video galleries of 3D reconstructions and animations obtained from CT scans. These images and case material are linked to audio galleries of sound recordings of some marine mammal species and for specimens for which necropsy reports and ecology data are available in case report files for registered users. Records of CT service requests, specimen inventories, and image archive inventories are also available on the site. Features of the database website include but are not limited to:

- User Defined Profiles
- Full Boolean search capabilities for all content including images, multimedia and text files.
- Literature and specimen case files with multiple search options; e.g., sort by publication type, year, author, title, keyword, etc.; export/import of citations in multiple formats; abstract and full text viewing capabilities; download full text or abstract as PDF files and upload of citations by users in multiple formats including EndNote, Tagged, XML and BibTex.
- Enhanced interactive image and video galleries with sample images and videos obtained from CT scans, 3D reconstructions and field and laboratory dissections as well as links to specific case images and data for individual specimens.
- Audio galleries with sample recordings of multiple species.
- Embedded PDF documents viewable without third party software
- Imaging request forms to permit off-site users to send material for CT imaging and interpretation
- Web form reports for administrators and laboratory staff displaying website CT service requests as spreadsheets and tables in multiple formats including xcl, dba, acc and mysql.
- RSS feed aggregators for WHOI News and BBC News on marine species and events
- Categorized forums for interdisciplinary discussions.
- Content commenting for website user feedback and questions.
- Event Calendars to provide users with a list of upcoming interdisciplinary events and virtual workshops.
- Categorized FAQ (frequently asked questions) section
- Integrated links to WHOI and other related websites and funding organizations
- Annotated anatomy with on-line tests available for students for formal K-12 integration.

Current Use Statistics (Google Analytics)

To date, the site has provided data for 149 users of which 52 were graduate students and postdoctoral fellows. There are 76 Registered Users who make use of full data sets and case histories. Site traffic has been monitored since its launch by Google Analytics. In the first quarter of its availability (May to August 31, 2011) the site produced 1400 unique visits; 72 % new visitors, 28 % returning visitors), 27,000 page views and 160 downloads of images and content worldwide. By 2012, the XML site maps were configured to automatically update several of the major search engines including Google,

Yahoo, and Bing. This design improved internet visibility with each search engine indexing session and two magnitudes of growth in use.

Website Activity Summary: May 1, 2011 to October 1, 2012

Page views: 129,894
Site Visitors: 21,547
Avg. Visit Duration: 00:04:14
Pages / Visit: 6.03
Traffic Sources:
58.40% Search Traffic
16.84% Referral Traffic;
24.77% Direct Traffic
Downloads: 1,533
370,000 Google listings

RESULTS

Unlike most research proposals, the principal goal of this project is not a set of incremental discoveries but rather to create a center that has two core activities:

1. To assist individual projects and diagnostic procedures for stranded animals through professional non-invasive imaging.
2. To create and augment the proposed web accessible database from the >1000 cases in the current Ketten laboratory image archive and to provide interpretations and data sets for those cases to the research community.
3. The compilation, categorization, and annotation of data sets acquired for specific user projects

The first year of this project was devoted largely to completion of the design and to testing accuracy and efficiency of each component in an operational website. The following 2 years were devoted to transitioning existing data to a web-accessible database and increasing the sophistication of the website as well as testing security of proprietary data for individual researchers. This final year focused on transitioning major file sets for the full range of archived species data and exploration of new protocols for challenging imaging subjects; e.g., high density, multi-meter coral cores, mega specimens, live invertebrates, deep sea cabling, and deep sea cores. To increase the value of the data, manuals on the scanning procedures used and interpretations of the data sets were completed and published as well.

IMPACT/APPLICATIONS

The potential for scan data is illustrated by the examples below taken from recent studies within this laboratory. As indicated by the datasets and by the publications list below, scan data is assisting a wide range of researchers and topics, ranging from climate change to in vivo diagnostics for stranding rehabilitation decisions.

At present, >100,000 images are available to transition to the site, comprising 9.1 TBytes of data and images. Only ~35% of these available datasets are represented on the website. Further, at present ~300 additional cases are scanned/year of which ~100 cases/year are strandings. Available data include 1012 cases scanned at slice resolutions of 0.1 to 5 mm from 175 species, including nearly a third of all cetaceans (34 species), 6 species of pinnipeds, 5 species of sea turtles, and multiple species of fishes, elasmobranchs (sharks and rays), invertebrates, land mammals, including humans, trauma and pathology cases, and non-biotics including Deep Sea geology cores and samples, gear, and moorings. The image sets available to be included on the site cover 176 species of marine and land species, including approximately 400 data sets for marine mammals alone.

Making this database available to the scientific community is critical for several research fronts attempting to solve impact issues; e.g., finite element and finite difference models (FEM/FDM) of acoustic propagation characteristics of different species, modeling tissue responses to over exposure, understanding differences amongst species for specific sound sources, and the education of stranding responders and pathologists in the recognition and interpretation of normal variants vs. pathologies in different post-mortem stages for marine mammals.

RELATED PROJECTS

Projects Employing CT DATASETS

Macro to Micro: Whole Body to Inner Ear

In Figure 1, 3D reconstructions of two species of odontocetes demonstrate significant differences in the structure, volume, and content of tissues that are critical to sound reception. By segmenting tissues in the heads of each species, based on their X-ray attenuations, which correspond to tissue sound transmission, it is possible to determine geometries fundamental to the frequency and acoustic attenuation characteristics. In both cases, fatty tissues are found to be pinnal analogues but also that these fatty "pinnae" are species specific. This implies that, like the pinnae and outer ear canals of land mammals, the fatty tissues are critical determinants of peak resonances and thus sensitivities of each species.

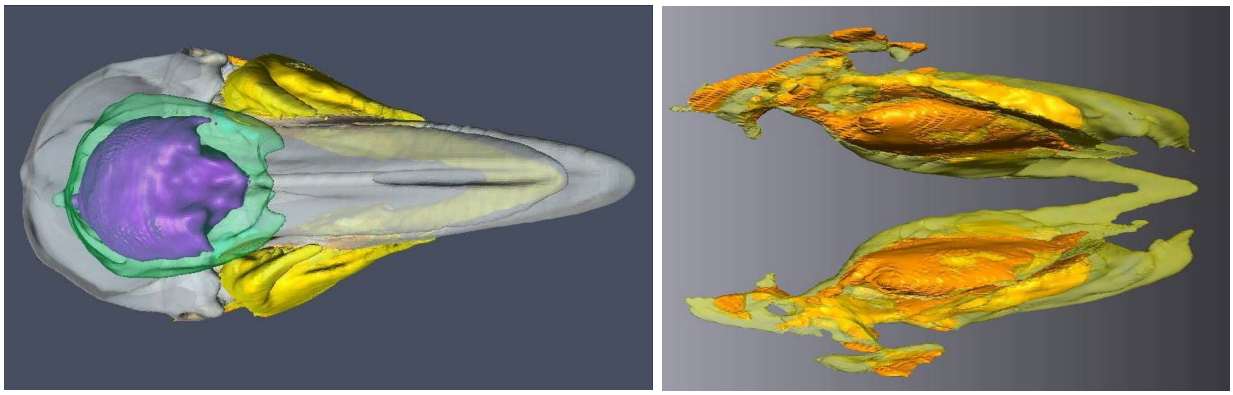


Fig. 1A. Dorsal view of head and fats, Common Dolphin, Delphinus delphis Melon core (purple); outer or theca of melon (green), jaw fat lobes (yellow). In each figure, a reconstruction of scans of the head of an intact specimen reveals the skull anatomy (transparent white), two components of the melon (outer layer green and inner core purple), and the multi-lobed fats aligning with and surrounding the mandible (gold) (see also: Ketten, D.R. 2008 Underwater ears and the physiology of impacts: Comparative liability for hearing loss in sea turtles, birds, and mammals. Bioacoustics, vol. 17, no. 1-3, pp. 312-315).

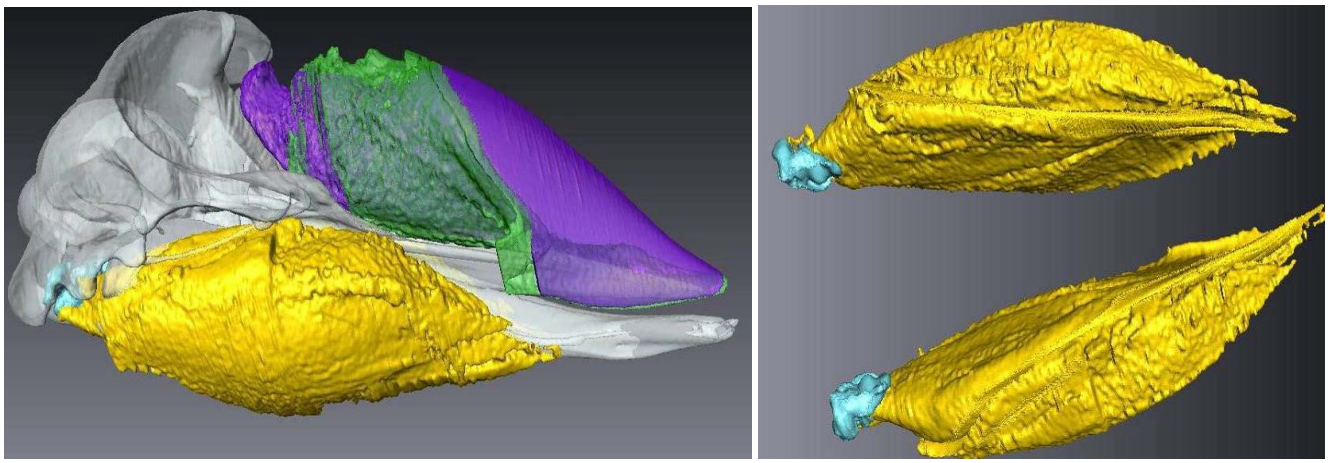
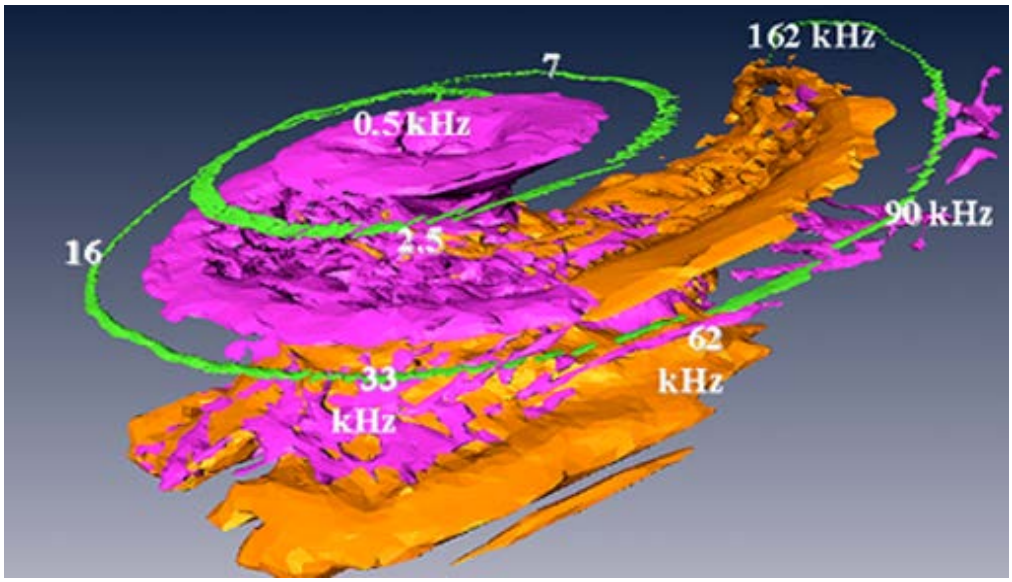


Fig. 1B. Lateral view of head and dorsal view of fats, Cuvier's Beaked Whale, Ziphius cavirostris Hearing Loss in Cetaceans. In each figure, a reconstruction of scans of the head of an intact specimen reveals the skull anatomy (transparent white), two components of the melon (outer layer green and inner core purple), and the multi-lobed fats aligning with and surrounding the mandible (gold) (see also: Ketten, D.R. 2008 Underwater ears and the physiology of impacts: Comparative liability for hearing loss in sea turtles, birds, and mammals. Bioacoustics, vol. 17, no. 1-3, pp. 312-315).

In Figure 2, CT images and 3D reconstructions of the inner ear of bottle nose dolphins are used to calculate sites of absence of auditory nerve fibers and thus corresponding frequencies of hearing loss in older animals. Comparisons of the predicted loss maps with the hearing curves of these animals show perfect correspondance for the maps with hearing abilities measured behaviorally. This exercise demonstrates the accuracy and potential for CT exams to determine the presence or absence of hearing deficits in stranded animals, pre or post mortem.



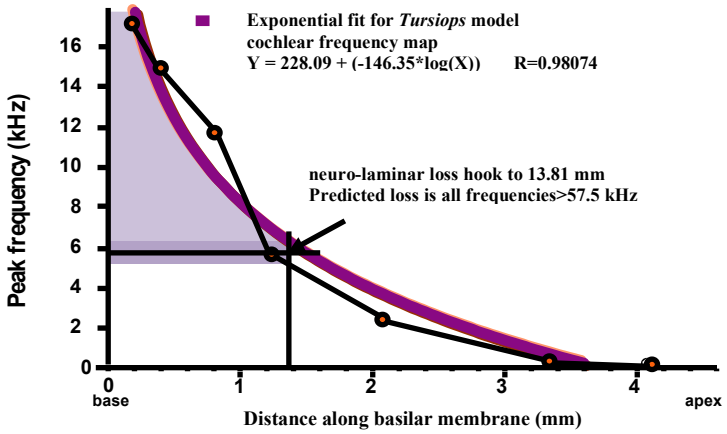


Figure 2A (top). 3D reconstruction of inner ear of bottlenose dolphin with superimposed frequency map.

Figure 2B (bottom). Calculation of bottlenose dolphin frequency map and position of ganglion cell losses related to hearing loss.

Tursiops truncatus inner ear imaged with CT to obtain frequency of hearing loss. Figure 2A shows the basilar membrane (green) auditory nerve (orange), and ganglion cells and fiber (purple) distributions. Estimates of frequency calculated for this ear are listed by position on the membrane. The lack of fibers beyond ~57 kHz suggests that this was the high frequency functional cutoff for this animal in its later life. A graph (Fig. 2B) shows the curve calculated for this ear for the frequency distributions. Celloidin histology of the ear confirmed the loss. Comparisons with the actual hearing responses show that this form of diagnosis with CT accurately predicts sensorineural hearing loss from aging and noise in this animal(Ketten et al 2010).

Sound Reception Modeling for Range and Sensitivity

The potential for scan data sets to improve and promote thesis research is shown in the following results from curent projects by Maya Yamato (WHOI, see Yamato et al 2012) and Andrew Tubelli (Boston Univ., Tubelli et al 2012), who are working collaboratively on minke whale tissues. Both are employing FEM techniques to address sound reception and transduction. Benchmarking is the first critical step for translating scan data to FEM compatible material property elements as shown in Figure 3.

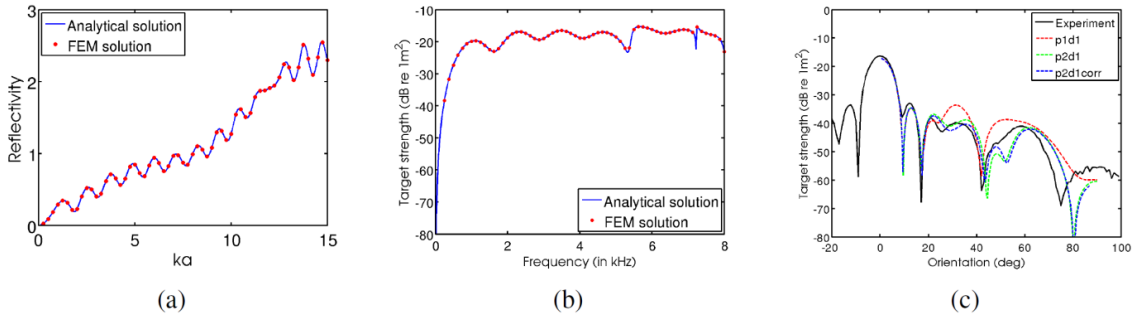


Figure 3. a) Back-scattering from a sphere with 0.8 contrast in sound speed relative to the medium. b) Scattering from an elastic sphere. (c) Comparison between measurements and finite element computations of backscattering from an aluminum disk.

For the actual studies, multiple intact minke whale heads have been scanned. These studies require approximately 4 hours of scanning time at the WHOI CSI facility because of the bulk of the tissue and voltages required to image, a task that would have been prohibitive at a clinical facility, and also was far less costly but yet provides equivalent or better resolution (100 micro sectioning) than industrial scanners. Access to dissection immediately following also enhances the ability to compare scan images to actual tissue conformations without interim freeze artifact or transport. In Figure 4, scans of an entire minke whale head were segmented for bone vs soft tissues implicated in sound transmission to the ear. Figure 5 provides simulation results for whole head plane wave ensonification from 3 views.

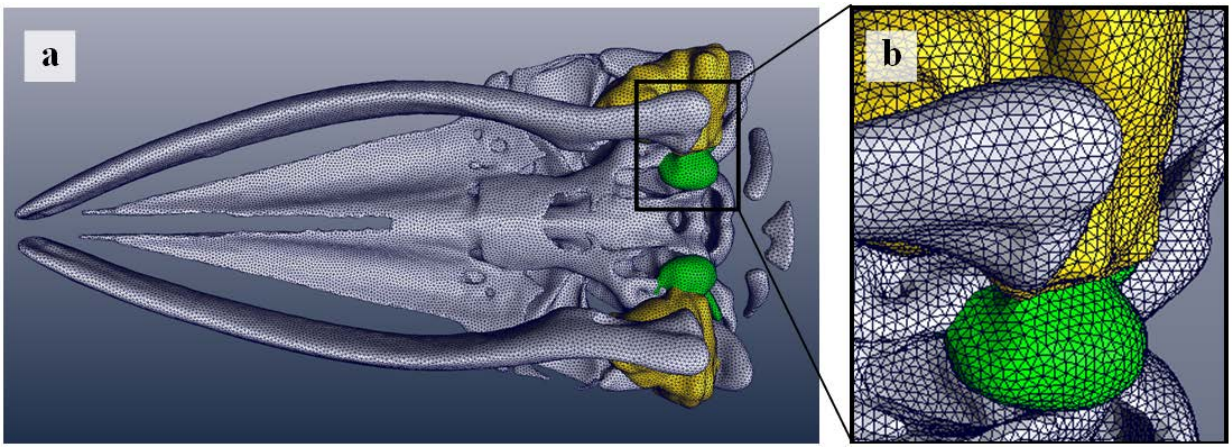


Figure 4. a) Preliminary FEM mesh of minke whale head showing only the skull (grey), ears (green), and fat bodies adjacent to the ears (yellow) for easier visualization (ventral view). b) Enlarged section of left ear region, showing details and the quality of the tetrahedral mesh, which can be further refined.

At the other end of the imaging spectrum, Tubelli is formulating FEM simulations for understanding the motion and transfer function of the middle ear, employing submillimeter scan data from the same head (Fig 6).

The studies show (Fig. 7) that the malleus-incus complex moves as one unit, bending unidirectionally about the anterior process of the malleus. The anterior process acts like a cantilever beam with the force of the glove finger pushing down at and deflecting the body of the malleus at all frequencies tested in the model. At low frequencies, the stapes acts like a hinge centered at the annular ligament where it connects to the larger crus. At high frequencies, the stapes exhibits the same motion as well as a rocking motion along the short axis of the elliptically-shaped footplate.

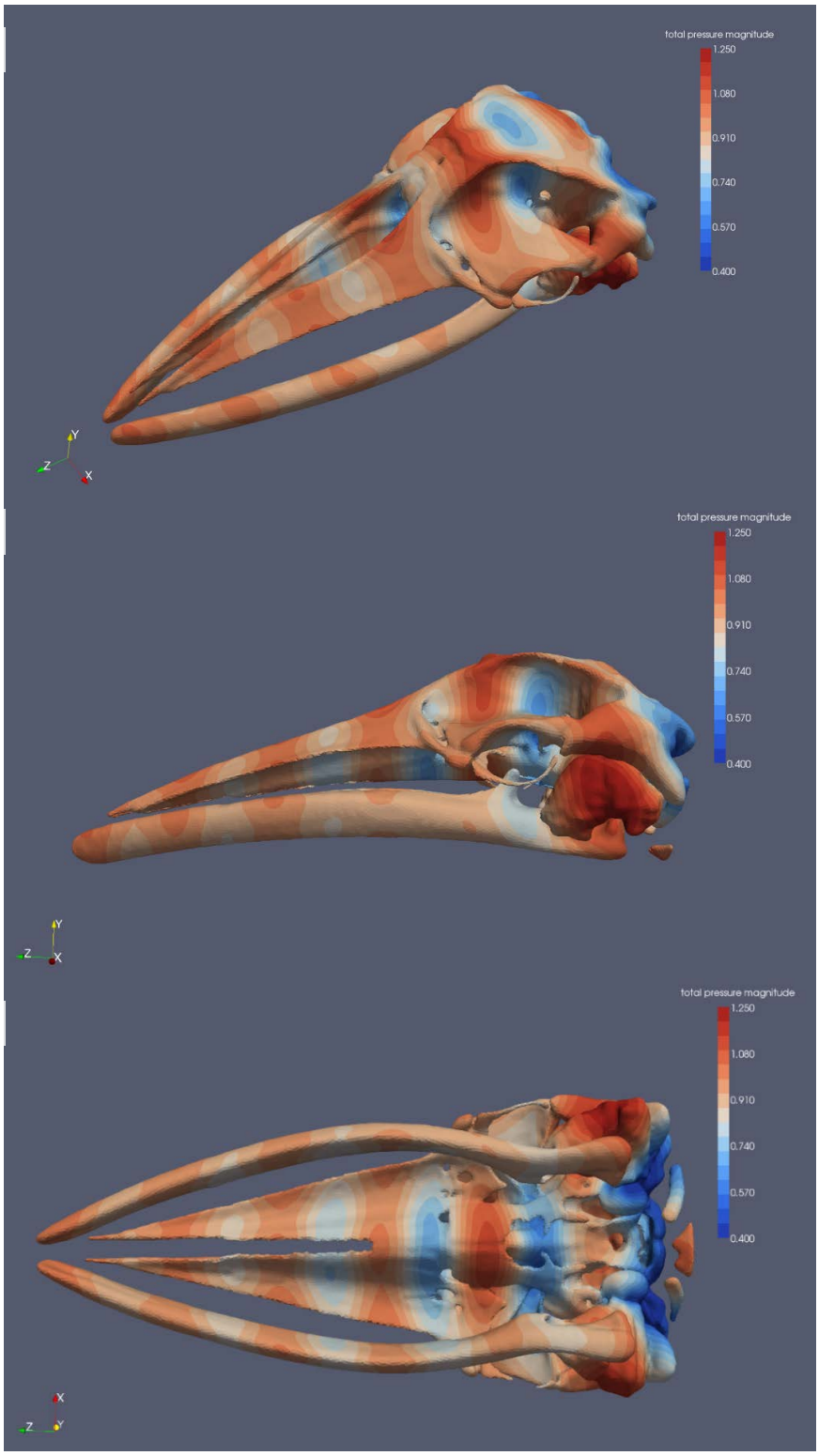


Figure 5. Preliminary results of an FEM simulation in which all tissues are treated as fluids in the model. The head is being ensonified by a 5 kHz plane wave with -z incident direction. a) Dorsal view; b) Lateral view; c) Ventral view. The magnitude of the total acoustic pressure field is shown so that interference patterns can be easily visualized.

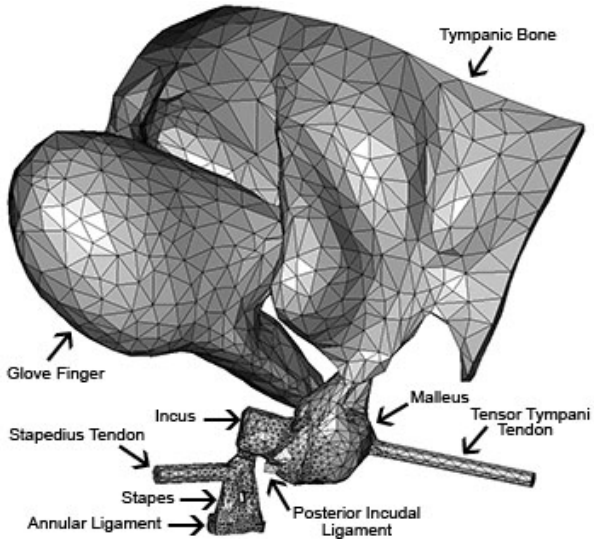


Figure 6. Model mesh consisting of 21,312 triangular elements.

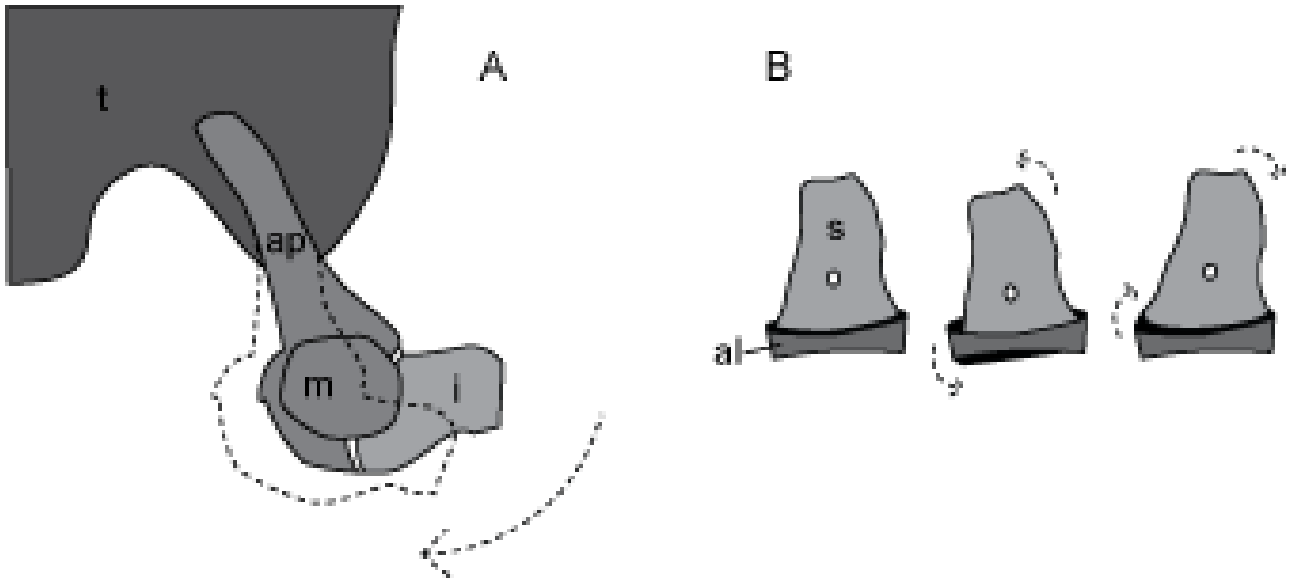


Figure 7. Motion of the malleus-incus complex (A) and stapes (B); t=tympanic bone, ap=anterior process, m=malleus, i=incus, s=stapes, al=annular ligament.

Assuming that the middle-ear transfer function plays an important role in shaping the audiogram, the model predicts that the frequency range of best hearing sensitivity is between approximately 100 Hz and 2 kHz. This falls within the vocalization frequencies recording for the species, between 50 Hz and 9.4 kHz.

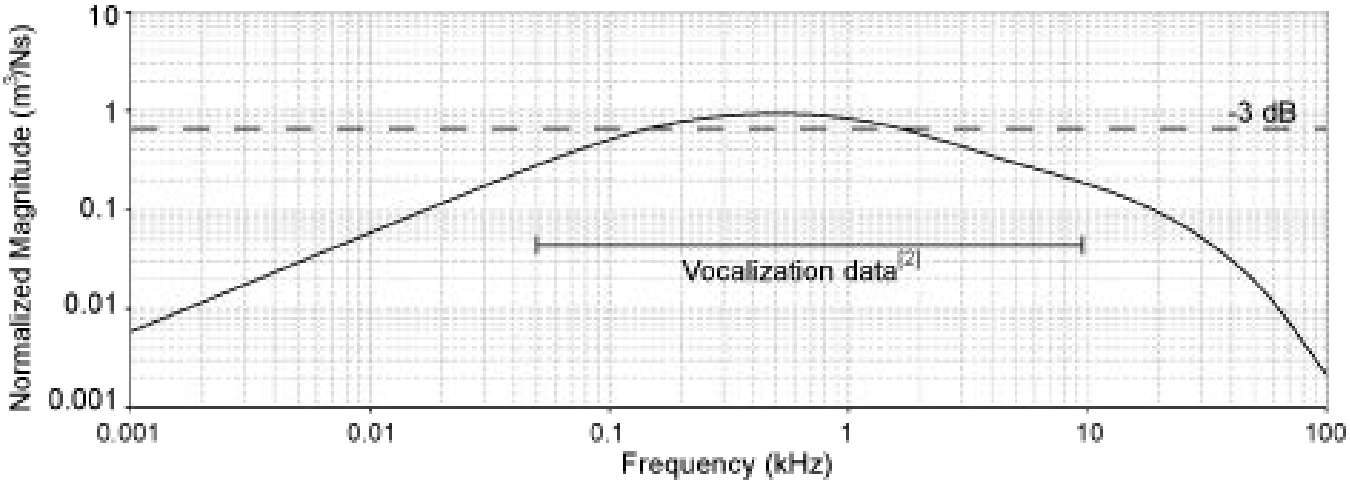


Figure 8. Middle-ear transfer function predicted by the model. (See Tubelli et al. 2012 in press)

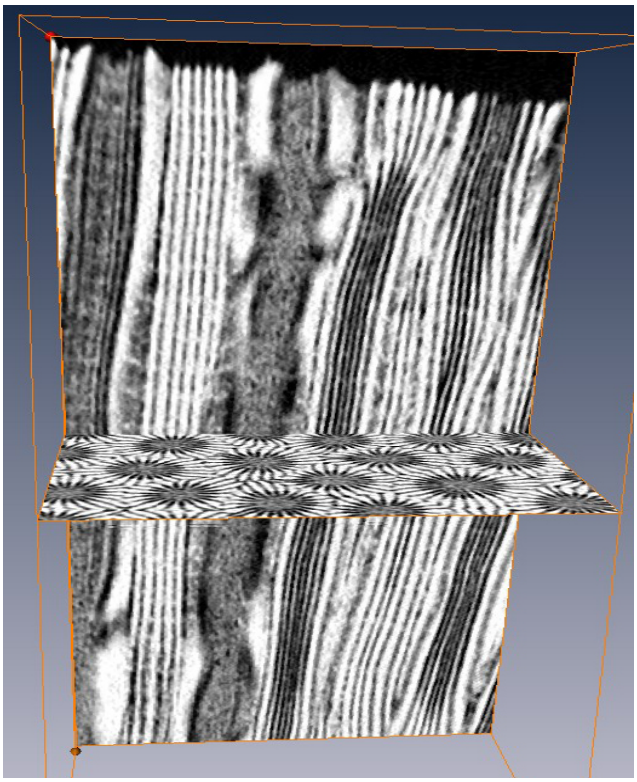
Additional studies are underway on both cetacean and chiropteran ears (Fig. 9) from micro-CT that are providing data on the fine structure and topology of the inner ear that will allow us to confirm the hypothesis that some echolocating abilities are dependent upon standing vs. traveling wave phenomena.

Figure 9. An 18 micron voxel micro CT of the inner ear of a Phocoena phocoena (harbor porpoise) ossicular chain and inner ear with a 22.5mm basilar membrane (yellow) with basal width of 30 microns, apical width of 290 microns, and post hook input is shown in a ventral view. The 3D reconstruction was created from 1700, 18 micron thick sections and demonstrates the relationship and relative dimensions of the major inner ear elements as well as the ossicular chain (Ketten et al 2012 in press).

RELATED PROJECTS

Datasets Added / Projects Assisted
A total of 1012 datasets were scanned and catalogued under the funding of this project, with 274 scanned in the last year alone. Of these, 52 cases were live or post mortem strandings. Notable cases imaged to date included the following (projects in **Bold** are funded through ONR):

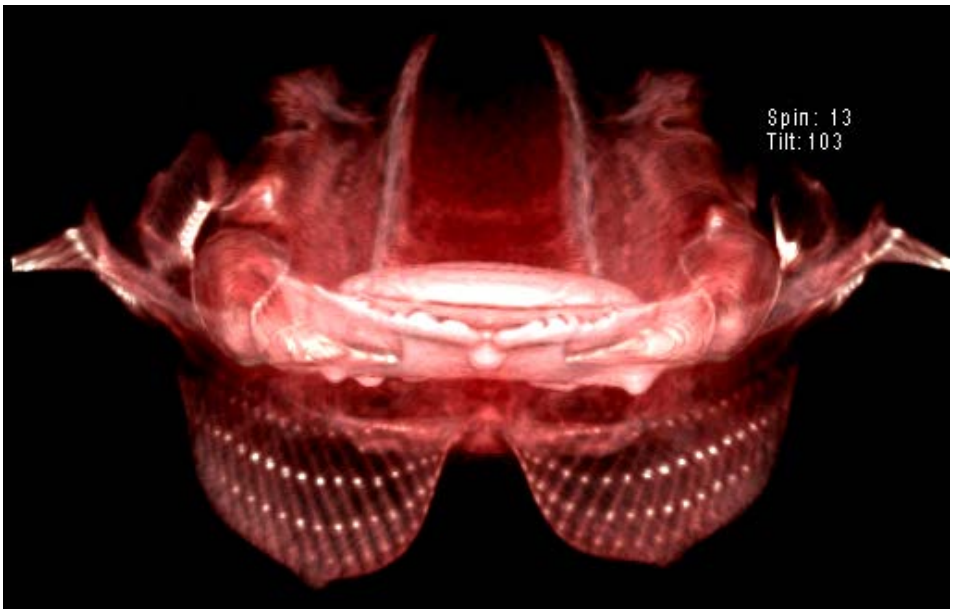
- Coral cores for climate change research (A. Cohen, WHOI, PI and visiting faculty and students from The Australian Nuclear Science & Technology Organization, The Biology Department at University of Puerto Rico & the Department of Earth and Planetary Sciences at University of California, Santa Cruz).



Longitudinal and cross-sectional projections from 100 micron imaging of a brain coral for climate dependent growth studies.

- **Stretch hoses (Applied Ocean Physics & Engineering department, WHOI, to evaluate wear and locate in mooring optical cables used in the Right Whale monitoring program)**
- Stromatolites for climate change research (J. Bernard, A. McIntyre-Wressnig, WHOI, PI)
- Humboldt squid (*Dosodicus gigas*)(Iliana Ruiz-Cooley,, NOAA-Southwest Fisheries Science Center to determine sensory system anatomy)
- **Live Midshipman and Lusitanian toadfish (R. Fay and R. Sisneros; Marine Biology Laboratory visiting post-doctoral and Grass Fellows, to evaluate otolith structure and relationships to the swim bladder).**

- Oil samples from the Deepwater Horizon spill (C Reddy , Marine Chemistry & Geochemistry Department ,WHOI, to evaluate pattern of rippling and visualize internal structure of deposits washing ashore)
- **Chondricthyes (Rays and Shark) for fin design and hydrodynamics (F. Fish Westchester University and R. Russo, University of Virginia Department of Mechanical & Aerospace Engineering, PI) and for determination studies of age and growth (S. Thorrold, WHOI)**



Spotted eagle ray, anterior view, demonstrating hyper mineralized jaws and nodes in ventral rays.

- **Narwhal flippers and flukes (F. Fish in association with Natalia Rybczynski, Canadian Museum of Nature-Research/ Paleobiology)**
- **Seals and pigs in pressure chamber (A. Fahlman, M. Moore, WHOI, PI)**
- **Cetaceans and seals for IFAW/NOAA NMFS for stranding diagnostics**

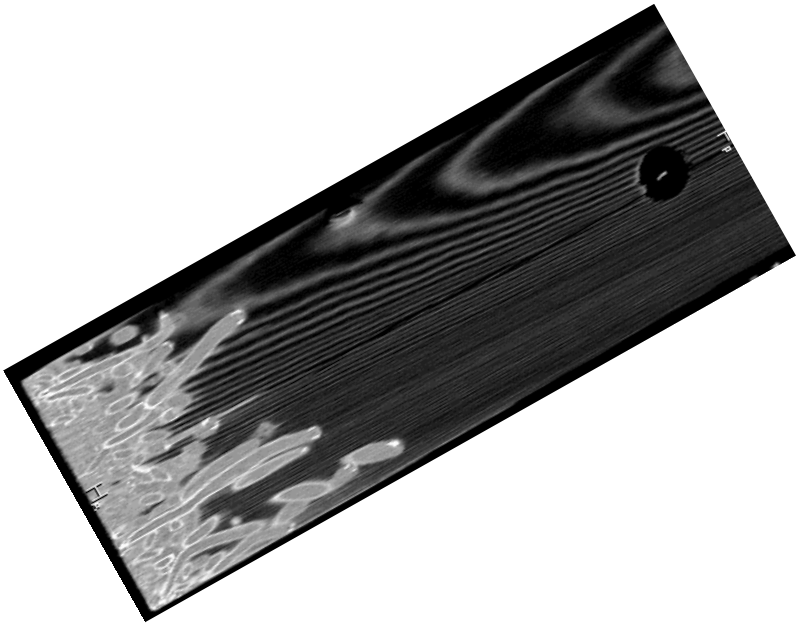
3D (left) and 2D (right) thin section of vertebrae of a young right whale showing evidence of traumatic scoliosis leading to aggravated bone degeneration and neural loss with probable paralysis.

- Turtle ear 3D reconstructions and fat volumes for hearing study (C. Carr, U. MD, PI)

Red ear slider turtle, 2D ventral view (see Carr et al, 2012).

- Terrapin diagnoses, *in vivo,* for National Marine Life Center (S. Rogers Williams, DVM)

- **Blue whale ears for stranding evaluation (J. Jacobsen, Humboldt State)**
- Shipworm infestation experiments (S. Gallagher, WHOI, PI)



Ship worm infestation and burrow pattern monitoring. Note the hyper bright points that are the radula or teeth that allow the clams to penetrate the wood pilings.

- **Minke whale head tissues (D. Ketten, WHOI, PI)**
- ***Ziphius cavirostris* ears, stranding evaluations (N. Hauser, Cook Islands, PI)**
- Tiger ears for LF hearing studies (E. Walsh, Boystown, PI)
- **Neophocoena phocaenoides stranding evaluations (W. Ding and D. Ketten, China, PI)**
- Sand lances for summer student project on cetacean prey species (S. Strobel, WHOI)
- **Cetacean and Chiropteran micro CT scans of the inner ear (for ultrasonic adaptations of aerial and aquatic biosonar, in collaboration with J Simmons, Brown Univ. and H. Riquimaroux, Doshisha University)**
- **Rubber stretch hose to evaluate defects in deep water buoys (L. l O'Hara, D. Peters, WHOI, PI)**
- **Micro-circuit boards to evaluate crystal defects (E. Gallimore, WHOI, PI)**
- **Tissue segmentations of whole cetaceans (K. Foote, WHOI, PI**
- **FEM of minke whale heads(M. Yamato, WHOI, student)**
- **Minke whale audiogram (A. Tubelli, Boston Univ., student)**

TOTAL USER BASE 2009 TO PRESENT
(ONR FUNDED IN BOLD)
BEHAVIOR

Diane Claridge Bahamas MARMAM Research Organization Marine Mammal Conservation
Dr. Caitlin O'Connell Stanford University Elephant Behavior
Dr. Jeheskel Shoshani The Elephant Research Foundation Elephant Conservation
Dr. Peter Tyack Woods Hole Oceanographic Institution Behavioral Acoustics
Dr. Susan Parks The Pennsylvania State University Marine Mammal Acoustics

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Dr. David Mountain Boston University Biomechanics
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Dr. J. Michael Jech Northeast Fisheries Science Center Fisheries Biology
Dr. Joeseph Sisneros University of Washington Fish Bioacoustics
Dr. Michaela Meyer Eaton Peabody laboratory/MEEI Auditory Physiology
Dr. Peggy Edds-Walton Marine Biological Laboratory Fish Bioacoustics
Dr. Richard Chadwick NIDCD/NIH Biomechanics
Dr. Richard Fay Boston University MBL Fish Bioacoustics
Dr. Soraya Moein-Bartol Virginia Weslyan College Sea Turtle Biology
Dr. Yuki Iwashina James Cook University Dugong Hearing
Maya Yamato WHOI - MIT Joint Program Mysticete Hearing

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Dr. Frank Fish West Chester University Hydrodynamics/Locomotion

NEUROPHYSIOLOGY
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Dr. Catherine Carr University of Maryland Neurobiology/Evolution
Dr. Eric Montie University of South Florida Neuroanatomy
Dr. Jelle Atema Marine Biological Laboratory - Boston University Sensory Systems
Dr. Jennifer Hammock Smithsonian National Museum of Natural History Olfaction
Dr. Jim Simmons Brown University Biosonar

Dr. Mario Svirsky New York University Human Auditory Physiology
Dr. Roger Hanlon Marine Biological Laboratory Cephalopod Neurophysiology

PATHOLOGY/STRANDING
Andrea Bogomolni Woods Hole Oceanographic Institution Pathology / Toxicology
Connie Merigo New England Aquarium Rescue & Rehabilitation
Dr. Antonio Mignucci Universidad Metropolitana Marine Mammal Conservation
Dr. Becky Woodward University of Maine Stranding Response
Dr. Craig Harms North Carolina State University Zoological Medicine
Dr. Donald Stremme University of Pennsylvania Exotic Animal Medicine
Dr. Michael Moore Woods Hole Oceanographic Institution Veterinary Pathology / Toxicology
Dr. Michael Murray Monterey Bay Aquarium Veterinary Sciences
Dr. Michelle Sims National Marine Life Center Veterinary Research
Dr. Regina Cambell-Malone Brown University Marine Mammal Anatomy
Dr. S. Roger Williams National Marine Life Center Clinical Pathology
Dr. Sophie Dennison Marine Mammal Radiology.com Veterinary Radiology
Dr. Tom deMaar Gladys Porter Zoo Veterinary Research
Dr. Tracy Romano Mystic Aquarium Neuroimmunology
Katie Touhey Cape Cod Stranding Network / IFAW Rescue & Rehabilitation
William McLellan University of North Carolina, Wilmington Anatomy and Physiology

SYSTEMATICS & EVOLUTION
Charles Potter Smithsonian Institution Evolution / Systematics
Dr. Heather Koopman University of North Carolina - Wilmington Biochemistry
Dr. Iliana Ruiz-Cooley Southwest Fisheries Science Center Marine Ecology & Fisheries
Dr. Jacqueline Webb University of Rhode Island Morphology/Sensory Biology
Dr. Jonathan Dale Hopkins Marine Station - Stanford University Ecology/Physiology
Dr. Joy Reidenberg Mount Sinai School of Medicine Anatomy
Dr. Martin Nweeia Harvard Medical School Dental Research
Dr. Robert Daniels New York State Museum Freshwater Fish Ecology
Dr. Tecumseh Fitch University of Vienna Evolution / Cognition
National Geographic National Geographic Conservation

UNDERWATER ACOUSTICS
Dr. Kenneth Foote Woods Hole Oceanographic Institution Applied Ocean Physics
Dr. Mark Grosenbaugh Woods Hole Oceanographic Institution Hydrodynamic Modeling
Dr. Hanumant Singh Woods Hole Oceanographic Institution Acoustics
Dr. Andone Lavery Woods Hole Oceanographic Institution Acoustics
Dr. Dezhang Chu Woods Hole Oceanographic Institution AOP&E
Dr. Timothy Stanton Woods Hole Oceanographic Institution Acoustics

PUBLICATIONS

33 Refereed, Published Articles Supported through this award

2012 Zosuls, A., S. O. Newburg, D. R. Ketten and D. C. Mountain. Reverse Engineering the Cetacean Ear to Extract Audiograms. In: The Effects of Noise on Aquatic Life, A. Popper and

A. Hawkins (eds). Advances in Experimental Medicine and Biology, Volume 730, pp.61-64. [published, refereed]

2012 Yamato, M., Ketten D. R., Arruda J. J., Cramer S. R., and Moore K. The auditory anatomy of the minke whale (Balaenoptera acutorostrata): a potential fatty sound reception pathway in a baleen whale, The Anatomical Record, 04/2012, Wiley Online Library, p.1-8. [published, refereed]

2012 Vigness-Raposa, K.J., G. Scowcroft, J. H. Miller, D.R. Ketten. Discovery Of Sound In The Sea: An On-Line Resource. In: The Effects of Noise on Aquatic Life, A. Popper and A. Hawkins (eds). Advances in Experimental Medicine and Biology, vol.730, pp. 135-138[published, refereed]

2012 Tubelli, A., A. Zosuls, D. R. Ketten and D. C. Mountain. Prediction of a Mysticete Audiogram via Finite Element Analysis of the Middle Ear. In: The Effects of Noise on Aquatic Life, A. Popper and A. Hawkins (eds). Advances in Experimental Medicine and Biology, vol.730, pp. 57-60. [published, refereed]

2012 Svirsky, M. A., M B Fitzgerald, A Neuman, E Sagi, C-T Tan, D R Ketten, and B Martin Current and planned cochlear implant research at New York University Laboratory for Translational Auditory Research, Journal of the American Academy of Audiology, vol.23, Issue 6, New York, p.422-437. [published, refereed]

2012 Mooney, TA, Hanlon, RT, Christensen-Dalsgaard, J, Madsen, PT, Ketten, DR, Nachtigall, PE (2010). "The potential for sound sensitivity in cephalopods." In: The Effects of Noise on Aquatic Life, A. Popper and A. Hawkins (eds). Advances in Experimental Medicine and Biology, vol.730, pp. 125-128. [published, refereed]

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2012 Lee, W.-J., A.C. Lavery, and T.K. Stanton "Orientation dependence of broadband backscattering from live squid," J. Acoust. Soc. Am. 131: 4461-4475. [published, refereed]

2012 Ketten, D.R., J. Simmons, H. Riquimaroux, S. Cramer and J. Arruda Cochlear structural variants in echolocators, Journal of the Acoustical Society of America, 04/2012, Volume 131, Issue 4, p.3423-3423. [published, refereed]

2012 Ketten, D.R. Marine Mammal Auditory System Noise Impacts: Evidence and Incidence. In: The Effects of Noise on Aquatic Life, A. Popper and A. Hawkins (eds). Advances in Experimental Medicine and Biology, vol. 730, pp. 207-212. [published, refereed]

2012 Jones, B.A., A.C. Lavery, and T.K. Stanton (2009), "Use of the distorted wave Born approximation to predict scattering by inhomogeneous objects: application to squid," J. Acoust. Soc. Am. 125: 73-88. [published, refereed]

2012 Foote, K., M. Hastings, D.R. Ketten, Y-T Lin, J. Reidenberg, and K. Rye. Sonar-induced pressure fields in a post-mortem common dolphin. Journal of the Acoustical Society of America, vol.13, Issue 2, p.1595-1604. [published, refereed]

2012 Derse Crook, E., Anne L. Cohen, Laura Hernandez-Terrones, Mario Rebolledo-Vieyra,and Adina Paytan (in review) Reduced calcification of a common Caribbean coral under extreme conditions of natural acidification, Nature Climate Change, [published, refereed]

2012 Cantin, N.E., Anne L. Cohen, Ann M. Tarrant, Julie Arruda, Darlene R. Ketten and Janice M. Lough (under review) Interspecific variability in the coral calcification response to rising ocean temperatures on a central Red Sea reef. Plos 1.

2012 Dennison S, Moore M, Fahlman A, Moore K, Sharp S, Harry C, Hoppe J, Niemeyer M, Lentell B, Wells R Bubbles in live stranded dolphins. Proceedings Royal Society B 279:1396-1404 doi: 10.1098/rspb.2011.1754[published, refereed]

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2011 Mooney, Aran T., Li Songhai, Ketten, D. R., Wang Kexiong, and Wang Ding Auditory temporal resolution and evoked responses to pulsed sounds for the Yangtze finless porpoises (Neophocaena phocaenoides asiaeorientalis), Journal of Comparative Physiology A Neuroethology, Sensory, Neural, and Behavioral Physiology, 12/2011, vol. 197, Issue 12, p.1149-1158. [published, refereed]

2011 Fontella, J, FE Fish, N Rybczynski, M Nweeia, and DR Ketten,. Three-Dimensional Geometry of the Narwhal (Monodon monoceros) Flukes in Relation to Hydrodynamics. Marine Mammal Science (DOI: 10.1111/j.1748-7692.2010.00439). Marine Mammal Science, p.1-10[published, refereed]

2011 Fahlman A, Loring S, Ferrigno M, Moore C, Early G, Niermeyer M, Lentell B, Wenzel F, Joy R, Moore M. Static inflation and deflation pressure-volume curves in excised lungs of marine mammals J. Experimental Biology 214:3822-3828 [published, refereed]

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2011 Hooker, S.K., A. Fahlman, M. J. Moore, N. Aguilar de Soto, Y. Bernaldo de Quirós, A. O. Brubakk, D. P. Costa, A. M. Costidis, S. Dennison, K. J. Falke, A. Fernandez, M. Ferrigno, J. R. Fitz-Clarke, M. M. Garner, D. S. Houser, P. D. Jepson, D. R. Ketten , P. H. Kvadsheim, P. T. Madsen, N. W. Pollock, D. S. Rotstein, T. K. Rowles, S. E. Simmons, W. Van Bonn, P. K. Weathersby, M. J. Weise,T. M. Williams, P. L. Tyack Deadly diving? Physiological and behavioural management of decompression stress in diving mammals. Proc. R. Soc. B Published online, doi: 10.1098/rspb.2011.2088 [published, refereed]

2010 Webb, J. F., Herman, J. L., Woods, C. F. and Ketten, D. R. The ears of butterflyfishes: 'Hearing generalists' on noisy coral reefs? Journal of Fish Biology, 77: 1434-1451. doi: 10.1111/j.1095-8649.2010.02765[published, refereed]

2010 Mooney, TA, Hanlon, RT, Christensen-Dalsgaard, J, Madsen, PT, Nachtigall, PE, Ketten, DR. 2010. Sound detection by the longfin squid (Loligo pealeii) studied with auditory evoked

potentials: sensitivity to low-frequency particle motion and not pressure. Journal of Experimental Biology, vol. 213:3748-3759[published, refereed]

2010 Cantin N.C., Cohen, A.L., Karnauskus K., Tarrant A.M, McCorkle D.C. Coral growth declines as temperatures rise in the central Red Sea, Science, 329(5989):322-325 [published, refereed]

2010 Bogomolni AL, Pugliares KR, Patchett K, Herzig SM, Harry CT, LaRocque JM, Touhey KM, Moore MJ Mortality Trends of Stranded Marine Mammals on Cape Cod and Southeastern Massachusetts between 2000-2006. Dis of Aq Organisms 88:143-155 [published, refereed]

2009 Saenger CS, Cohen AL, Oppo DW (2009), Atlantic sea surface temperature trends and variability since 1552, Nature Geoscience, doifinder/10.1038/ngeo552 [published, refereed]

2009 Filadelfo, R., Pinelis, Y. K., Davis, S., Chase, R., Mintz, J., Wolfanger, J., Tyack, P. L., Ketten, D. R., and D'Amico, A. Correlating whale strandings with Navy excercises off Southern California. Aquatic Mammals, vol. 35 no. 4 pp. 452-472[published, refereed]

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2009 Moore M. Current issues facing North Atlantic right whales and stakeholders. Boston College Environmental Affairs Law Review 36:309-317 [published, refereed]

2009 Jones, B.A., A.C. Lavery, and T.K. Stanton (2009), "Use of the distorted wave Born approximation to predict scattering by inhomogeneous objects: application to squid," J. Acoust. Soc. Am. 125: 73-88. [published, refereed]

2009 LT Greg Dietzen (MS, MIT/WHOI; 2008) "Acoustic scattering from sand dollars (Dendraster excentricus): Modeling of high aspect ratio oblate objects and comparison to experiment". MIT/WHOI Master's thesis.

2009 Moore M, Bogomolni A, Dennison S, Early G, Garner M, Hayward B, Lentell B, Rotstein D: Gas bubbles in seals, dolphins and porpoises entangled and drowned at depth in gill nets. Veterinary Pathology 46: 536-547[published, refereed]

5 In Press

2012 Vásquez-Bedoya, L. F., A. L. Cohen, D. W. Oppo, and P. Blanchon (2012), Corals record persistent multidecadal SST variability in the Atlantic Warm Pool since 1775AD, Paleoceanography, doi:10.1029/2012PA002313, [in press, refereed].

2012 Tubelli, A., A. Zosuls, D. Ketten, M. Yamato, and D. Mountain. A prediction of the minke whale (*Balaenoptera acutorostrata*) middle-ear transfer function. 10 pp. in press, Journal of the Acoustical Society of America. [in press, refereed]

2012 Ketten, D.R., J. Simmons, H. Riquimaroux, S. Cramer, J. Arruda. Critical Cranial and Cochlear Structures in Echolocators. Proceedings of the 11th European Conference on Underwater Acoustics. 5 pp. in press, Journal of the Acoustical Society of America. [in press, refereed]

2012 Ketten, D.R. Underwater Hearing Impacts: Causes, Severity, and Types of Hearing Loss in Marine Species. Proceedings of Ocean Acoustics, 12 pp. [in press, refereed].

2012 Ketten, D.R., T.A. Mooney, S. Cramer, J. Arruda. Evidence of hearing loss in marine mammals via Auditory Evoked Potentials (AEP), Otoacoustic Emissions (OAE), and

Computerized Tomography (CT). Proceedings of the 11th European Conference on Underwater Acoustics. 5 pp. in press, Journal of the Acoustical Society of America [in press, refereed]

51 Plenary/Keynote Lectures/Published Abstracts Acknowledging this Award

2012 Hernández-Pacheco,Raisa, Anne L. Cohen, and Edwin Hernández-Delgado. Using coralskeletal growth parameters to predict tolerance of thermal stress. Paper presented at the 12th International Coral Reef Symposium 9-13 July 2012 Cairns, Queensland, Australia[refereed]

2012 Shorter, K. A. , T. Hurst, M. Johnson, S. Cramer, D. Ketten, M. Moore. Suction and skin: the effect of vacuum loading on the skin of a common dolphin. American Society of Biomechanics, Abstracts, 189-190.

2012 Ketten, D.R., J. Simmons, H. Riquimaroux, S. Cramer, J. Arruda. Cochlear Structural Variants in Echolocators. Special Session on Biosonar: Joint meeting: Acoustical Society of America (ASA), Acoustical Society of China (ASC), Western Pacific Acoustics Conference (WESPAC) and the Hong Kong Institute of Acoustics (HKIOA), Journal of the Acoustical Society of America, 04/2012, Volume 131, Issue 4, p.3423-3423.

2012 Ketten, D.R., J. Simmons, H. Riquimaroux, S. Cramer, J. Arruda. Critical Cranial and Cochlear Structures in Echolocators. Biomimetics Special Session 11th European Conference on Underwater Acoustics (ECUA 2012), Edinburgh, UK

2012 Ketten, D.R. Underwater Hearing Impacts: Causes, Severity, and Types of Hearing Loss in Marine Species. Ocean Acoustics 2012, Third International Conference on Ocean Acoustics, Office of Naval Research Ocean Acoustics Program, The Chinese Academy of Sciences, National Natural Science Foundation of China, Beijing, China.

2012 Ketten, D.R. Modeling Minke Whale Hearing: Anatomical Substrates of Hearing. 2nd Programme Review Meeting of the Joint Industry Programme (JIP) on Exploration & Production Sound and Marine Life. Herndon, VA.

2012 Bosshart, Sara, Anne Cohen, Delia Oppo and Stephanie Henson. Assessing the dominant controls on coral growth: implications for reef responses to climatechange. Paper presented at the 12th International Coral Reef Symposium 9-13 July 2012 Cairns, Queensland, Australia[refereed]

2012 Barkley, Hannah, Anne Cohen, Yimnang Golbuu, Elizabeth Mcleod, Rod Salm. Corals in highly variable environments are more resilient to ocean warming. Paperpresented at the 12th International Coral Reef Symposium 9-13 July 2012 Cairns, Queensland, Australia[refereed]

2012 Ketten, D.R., T.A. Mooney, S. Cramer, J. Arruda. Evidence of hearing loss in marine mammals via Auditory Evoked Potentials (AEP), Otoacoustic Emissions (OAE), and Computerized Tomography (CT). Hearing Physiology Special Session 11th European Conference on Underwater Acoustics (ECUA 2012), Edinburgh, UK

2012 Ketten, D.R., D Wang, T.A. Mooney, S Li, K Wang. Rivers to Open Ocean: Evidence for Marine Mammal Hearing Impacts. Sensory World of Fish and Fisheries: The Impact of Human Activities, Shanghai Ocean University

2011 Yamato, M., Ketten D. R., Arruda J. J., Cramer S. R., & Moore K. The auditory anatomy of the Minke Whale (*Balaenoptera acutorostrata*): Insights into potential sound reception

pathways in a baleen whale. 19th Biennial Conference on the Biology of Marine Mammals. Abstracts, 319.

2011 Tubelli, A. A., Zosuls A. L., Ketten D. R., & Mountain D. C. The effects of mechanical property manipulation on Minke Whale hearing sensitivity. 19th Biennial Conference on the Biology of Marine Mammals. Abstracts, 296-297.

2011 Mooney, TA, S Li, D R Ketten, K Wang, D Wang Hearing pathways in the finless porpoise, *Neophocaena phocaenoides*, and implications for noise impacts. J. Acoust. Soc. Am. Volume 129, Issue 4, p. 2431.

2011 Mooney, TA and DR Ketten Using Auditory Evoked Potentials to Examine Hearing Loss in Aquatic Animals: From Marine Mammals to Squid. Assoc. for Rsch in Otolaryngology, Baltimore, MD.

2011 Mooney, A. T., Li S., Ketten D. R., Wang K., & Wang D. Hearing pathways of the finless porpoise: Form and function in an 'unrepresentative' species. 19th Biennial Conference on the Biology of Marine Mammals. Abstracts, 209-210.

2011 Ketten, D.R., Shoshani, J., Arruda, J., Cramer, S., Reidenberg, J., Yamato, M. Great ears: Functional comparisons of land and marine leviathan ears, Tetrapod Evolution: Return to Water,, San Diego, CA.

2011 Ketten, D.R. Noise Impacts in Air-Adapted Ears: Mechanisms of Damage, Recovery, and Permanent Loss. International Bioacoustics Congress, La Rochelle, France

2011 Ketten, D.R. Hearing Risks in Underwater Ears: What the Incidence of Hearing Impairment in Wild Animals May Tell Us about Potential Impacts. NATO Conference on Effects of Sound on Marine Mammals, Amsterdam, Netherlands.

2011 Ketten, D. R., Mooney A. T., Williams R. C., Matassa K., Patchett K., Arruda J. J., et al. Hearing Loss in Harbor Seals: Differential Diagnoses of Conductive and Sensorineural Losses via Auditory Evoked Potentials (AEP), Otoacoustic Emissions (OAE), and Computerized Tomography (CT). 19th Biennial Conference on the Biology of Marine Mammals. 156.

2011 Ketten, D R, C R Williams, TA Mooney K Matassa, and K Patchet *In vivo* measures of hearing in seals via auditory evoked potentials, otoacoustic emissions, and computerized tomography. The Journal of the Acoustical Society of America 129, p. 2431.

2011 Fontanella, J. E., Fish, F. E., Rybczynski, N., Nweeia, M. and Ketten, D. R. Three-dimensional geometry of the narwhal (*Monodon monoceros*) flukes in relation to hydrodynamics. Society for Integrative and Comparative Biology.

2010 Zosuls, A., S. O. Newburg, D. R. Ketten and D. C. Mountain. Reverse Engineering the Cetacean Ear to Extract Audiograms. 2nd International Conference of the Effects of Noise on Aquatic Life, Cork, Ireland.

2010 Vigness-Raposa, KJ, G Scowcroft, J H Miller, DR Ketten Discovery of Sound in the Sea: An On-line Resource. 2nd International Meeting on The Effects of Noise on Aquatic Life. Cork, Ireland.

2010 Tubelli, A., A. Zosuls, D. R. Ketten and D. C. Mountain. Prediction of a Mysticete Audiogram via Finite Element Analysis of the Middle Ear. 2nd International Conference of the Effects of Noise on Aquatic Life, Cork, Ireland

2010 Mooney, TA, Hanlon, RT, Christensen-Dalsgaard, J, Madsen, PT, Ketten, DR, and Nachtigall, PE. The hearing of the longfin squid (*Loligo pealeii*) and sensitivity to low frequency noise. 2nd International Meeting on the Effects of Noise on Aquatic Life. Cork, Ireland.

2010 Mooney, TA, Hanlon, RT, Christensen-Dalsgaard, J, Madsen, PT, Ketten, DR and Nachtigall, PE. What squid hear: An evoked potential study of the longfin squid (Loligo pealeii). Association for Research in Otolaryngology, Anaheim Calif.

2010 Ketten, D.R. Marine Mammal Auditory System Noise Impacts: Evidence and Incidence. 2nd International Meeting on the Effects of Noise on Aquatic Life. Cork, Ireland.

2010 Ketten, D. R., Arruda, ,J., S. Cramer, Dunn, M., and Ridgway, S. Mature Mammal Hearing Loss: A Natural Experiment in Presbycusis. Association for Research in Otolaryngology, Anaheim Calif.

2010 Ketten , D.R., J. Arruda, S. Cramer, and M. Dunn Cochlear Morphometrics from CT: Length, Insertion, and Neuronal Distribution Estimates. Objective Measures in Auditory Implants, 6th International Symposium, St. Louis, Mo.

2010 Christensen-Dalsgaard, J, CE Carr,, PT Madsen, C Brandt, K Willis, D Ketten, P Edds-Walton, R R. Fay Specialisation for underwater hearing in the red-eared slider turtle, *Trachemys scripta elegans* Association for Research in Otolaryngology, Anaheim Calif.

2010 Christensen-Dalsgaard, J, CE Carr,, PT Madsen, C Brandt, K Willis, D Ketten, P Edds-Walton, R R. Fay Underwater hearing in the red-eared slider turtle, *Trachemys scripta elegans.* International Society for Neuroethology

2009 Yamato, M., Mooney, T.A., Ketten, D.R., Cramer, S. Arruda, J. Auditory anatomy and sound reception in the beluga whale (Delphinapterus leucas) compared to the bottlenose dolphin (*Tursiops truncatus*). 18th Biennial Conference on the Biology of Marine Mammals, Quebec, Canada.

2009 Yamato, M., D.R. Ketten, H. Koopman, G. Feijoo, J. Arruda, S. Cramer, and S. Sharp Hearing in baleen whales: Learning from stranded animals. Northeast Regional Stranding Conference (NERSC), Salem, MA

2009 Southall, B. L., Bowles A. E., Ellison W. T., Finneran J. J., Gentry R. L., Greene, Jr. C. R., D. Kastak, D. R. Ketten, J. H. Miller, P. E. Nachtigall, W. J. Richardson, J. A. Thomas and P. L. Tyack. Marine mammal noise exposure criteria: initial scientific recommendations. Proceedings of the 157th Meeting of the Acoustical Society of America. 125, 2517.

2009 Moore, MJ; Arruda, J; Cramer, S; Hammar, T; Ketten, D, Moore, C; Fahlman, A; Dennison, S Hyperbaric computed tomography: a novel tool to quantify the behavior of air-filled structures and gas emboli in cetacean and pinniped carcasses under a range of pressures. 18th Biennial Conference on the Biology of Marine Mammals, Quebec City, Quebec, Canada.

2009 Mooney, TA, Ketten, DR, Hanlon, RT, Christensen-Dalsgaard, J, Madsen, PT, and Nachtigall, PE. Squid hearing and their ability to detect echolocating predators. Office of Naval Research, Marine Mammals and Oceanography Program Review, Alexandria, VA.

2009 Mooney, TA, Hanlon, RT, Christensen-Dalsgaard, J, Madsen, PT, Ketten, DR and Nachtigall, PE. Detecting echolocating odontocetes: Can squid hear toothed whale predators? 18th Biennial Conference on the Biology of Marine Mammals, Quebec, Canada.

2009 Mooney, TA, and Ketten, DR. The why and how of testing hearing in stranded animals. Northeast Regional Stranding Network Conference. Salem, MA.

2009 M. Yamato, T.A. Mooney, D.R. Ketten, S. Cramer, and J. Arruda Auditory anatomy and sound reception in the beluga whale (Delphinapterus leucas) compared to the Bottlenose Dolphin (Tursiops truncatus). Office of Naval Research, Marine Mammals and Oceanography Program Review, Alexandria, VA.

2009 Ketten, D.R. Whale and Bat Sonar: Imaging to Understand Convergence, Divergence, and Parallelism Hadassah Hospital, Dept. of Otolaryngology, Special Lecture for the Neurosciences, Jerusalem, Israel.

2009 Ketten, D.R. Underwater Ears and Potential Impacts: What whales can and cannot hear. Israeli Zoological Society, Keynote Lecture, University of Tel Aviv, Tel Aviv, Israel.

2009 Ketten, D. R., Ridgway, S., Arruda, ,J., Dunn, M., Hammock, J., and J., Prahl, S., Williams, S.R. Marine Mammal Hearing Loss: Repeat that, please? 18th Biennial Conference on the Biology of Marine Mammals. Quebec, Canada.

2009 Ketten, D. R., Yamato, M., Clark, C., Ellison, W., Mountain, D., Zosuls, A. Mysticete Hearing: Basso, Biosonar, or Both? Invited paper 5th Animal Sonar Symposium, Kyoto, Japan.

2009 Ketten, DR Database Development for Ocean Impacts: Imaging, Outreach, and Rapid Response, Office of Naval Research, Marine Mammals and Oceanography Program Review, Alexandria, VA.

2009 Williams, C.R. and D.R. Ketten, The Use of Positional Computerized Tomography (CT) to Determine the Presence of Free Gas in the Coelom of a Sea Turtle. Northeast Regional Stranding Conference, Salem, MA.

2009 Tubelli, A, A. Zosuls, DR Ketten, DC Mountain,. Prediction of a Mysticete Audiogram via Finite Element Analysis of the Middle Ear, 18th Biennial Conference on the Biology of Marine Mammals, Quebec City, Quebec, Canada.

2009 Landry, S., S.M. Sharp, D. R. Ketten, M.J. Moore, B. Sharp, and K.M. Touhey. Understanding a Minke Whale Entanglement Case from a Variety.of Angles New England Regional Stranding Conference (NERS), Salem, MA

2009 Cramer, S., D. R. Ketten, J. Arruda, S. R. Williams, M. Yamato, C. Merigo, K.Touhey, and A. Mooney. Computed Tomography (CT): A non-invasive technique for assessing trauma and disease in stranded marine mammals, 18th Biennial Conference on the Biology of Marine Mammals, Quebec City, Quebec, Canada.

2009 Cramer, S., D. R. Ketten, J. Arruda, S. Prahl, S. R. Williams, and B. Dunnigan. Computerized tomography (CT) techniques for analysis of trauma and disease in marine mammals. Northeast Regional Stranding Conference (NERSC), Salem, MA

2009 Arruda, J., J.S. Reidenberg, S. Cramer, D.R. Ketten, and J.T. Laitman. "Lop-sided" odontocetes: A CT investigation of structural and functional asymmetry in the hyoid, laryngeal, and pharyngeal regions, Northeast Regional Stranding Conference (NERSC), Salem, MA

2009 Arruda, J., D. R. Ketten, Cramer, S., M. Yamato,. Computed Tomography (CT): 3D Visualization Of The Odontocete Melon Using Computerized Tomography, 18th Biennial Conference on the Biology of Marine Mammals, Quebec City, Quebec, Canada.

HONORS/AWARDS/PRIZES

Awarded to D.R. Ketten, WHOI and Harvard Medical School:

2012	Elected by the Science Council, Member of the Corporation of the Marine Biological Laboratory, 124th Class
2011	Functional MRI, Honors Fellowship, Martinos Imaging Center, Harvard Medical School
2010	Marine Mammal Research Fellow, Aquatic Mammals, European Cetacean Society

Awarded to M. Yamato, WHOI Joint Program

2011	Prescott Award for Best Student Presentation, Society for Marine Mammalogy, Biennial Meeting, Tampa, FL